

SUBMARINE MEDICINE

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(With two charts)

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IT IS my pleasure to present a diversified report covering many subjects under consideration during the past seven years of submarine duty. This report will consist of facts and conclusions crystallized from the experience of a field worker rather than in an academic review of the literature.

Submarine medical problems arise primarily from the association of men forced to breathe the same air while cruising under water and forced to live in close quarters without adequate hygienic facilities.

Slowly but surely, however, improvement in living conditions has been brought about so that the ten day patrol run at the present time is undertaken with less hardship than the overnight cruise at the time of the world war in 1914. Illustrating the arduous conditions under which submarine personnel existed at the beginning of the world war is the diary of Lieutenant Johannes Speiss, the only German submarine officer to serve continuously throughout the entire period of the world war.

As watch officer under Captain Weddigen of the *U-9*, the submarine which inaugurated undersea warfare by sinking the British cruisers *Aboukir*, *Cressy*, and *Hogue*, he relates that overnight cruises (October, 1912) were avoided since they were not only considered highly uncomfortable but unhealthy. Speaking of his submarine he states, "In order to live at all in the officer's compartment a certain degree of "finesse" was required. The watch officer's bunk was too small to permit one to lie on his back. One was forced to lie on one side and then, being wedged in between the bulkhead to the right and the clothes-press on the left, to hold fast against the movements of the boat in the seaway. The occupant of the boat could not sleep with his feet aft as there was an electric fuse box in the cabin directly overhead. At times the cover of this box was sprung and it was easily possible to cause an electric short circuit by touching this with the feet."

Cooking at that time was done topside on a gasoline stove; gasoline engines instead of Diesels propelled the boats and consequently poisoning from gasoline fumes was common. Speiss states, "One awoke in the morning with considerable mucous in the head and frequently with the so-called oil head." Living in a submarine was like living in a damp cellar since moisture inside the submarine condensed on the steel hull

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plates which were cooled by the low temperature of the sea water. The practice of taking opium to avoid bowel movements at sea was said to be common among German submarine officers since a five day period of constipation was preferable to challenging the inadequate toilet facilities. Describing these facilities Speiss states with reference to the central compartment, "In a small corner of this space was the toilet separated by a curtain, and after seeing this arrangement, I understood why the officer I relieved had recommended the use of opium before all cruises which were to last over twelve hours."

Today refrigeration and attempts at air conditioning have improved conditions but overcrowding, lack of bathing facilities and the necessity for rebreathing air in submerged cruising continue to exist. Because of these factors enhancing as they do the spread of contagious disease, because the complement of men on a submarine is reduced to a minimum, and because medical care is lacking when the submarine is operating, we have developed in submarine medicine the basic principle of selecting the most able men physically and mentally, and of keeping these men in the finest possible condition.

We seek to select rugged men, men who don't get sick. As on the football gridiron there is a sturdy type of individual who seldom gets hurt, comparably also in submarines there is an alert, rugged type of man who seldom appears at the sick bay, who does not develop the minor injuries and frequent upper respiratory tract infections which so heavily decrease the efficiency of naval personnel, and who, providentially, does not develop acute appendicitis in the middle of the Pacific Ocean.

This principle of careful selection and training of men is brilliantly exemplified further by the conduct of German submarine personnel who in the closing days of the war remained loyal and ready for concerted action in the face of mutiny, and collapse on the surface vessels.

A former submarine commander in our Navy made the following comment, "It was the opinion of all navies prior to the war that the duration of a submarine's stay at sea was a function of the ability of the crew to stand the strain rather than the amount of fuel and provisions she could carry. Yet as the war progressed submarines remained for longer and longer periods at sea. Did the men have more fortitude than was earlier credited to them, or did the selection of men and carefully controlled rest periods in port accomplish this? Probably both, but can anything more dramatically point out the submarine medical officer's function in increasing the effectiveness of a prime military weapon?"

It must ever be remembered that several men or even one man failing or careless in the performance of his duty as a result of physical or

mental weakness can send a submarine to the bottom of the ocean. We recall such incidents as that of a submarine during a submerged cruise suddenly descending from a depth of 90 feet to 180 feet during several minutes of inattention on the part of the operating personnel; or again, of a chief petty officer who while cruising in a submarine became violently insane as a result of meningo-vascular syphilis; and finally of a thoughtless seaman who opened a hatch prior to submergence. Incidents such as these provoke thoughtful concern and makes one realize the fragility of the human factor that separates safety from tragedy aboard a submarine.

It should be remembered also that because of shortage of space the complement of men aboard a submarine is reduced to a minimum. A loss of four men, for example, from one of the smaller boats reduces the complement ten per cent; on a battleship this percentage would mean approximately 120 men. Such a loss places an additional burden on the remaining men who for the most part are highly trained in their particular tasks and may not be able to assume additional duty without loss of efficiency.

It would appear that the principle of selecting the most able men for submarine duty would be unhesitatingly accepted. However, some years ago when stringent qualifications for submarine duty were drawn up, one of our most brilliant medical officers rejected them with the statement that the qualifications for general duty in the Navy would also serve to qualify men for submarines.

This unwise opinion, fortunately, did not take hold since the inauguration in 1929 and subsequent development of the submarine escape drill demanded men who were superior mentally and physically to the average in the service. This escape practice brought to light the alarmingly poor condition of the men in submarines at that time.

In 1932, 453 men were examined following a cruise in submarines from San Diego to the Hawaiian Islands. Of this number 25 per cent or 1 out of 4 failed to qualify for escape training. Of this percentage, 11.5 per cent of the men were unable to equalize pressure because of auditory tube obstruction. Four per cent suffered from colds, tonsillitis, and bronchitis. One half of one per cent had sinusitis and one and one half per cent had otitis media. Of the 25 per cent rejections, 18 per cent were the result of upper respiratory tract and ear, nose, and throat infections. Three per cent of the remaining 7 per cent were nervous, refused to use the escape appliance, or showed other manifestation of an abnormal psyche. In fact, men temperamentally unfit for submarine duty are automatically weeded out by submarine escape training.

Of the physical defects which did not disqualify candidates from

escape training, those relating to the teeth deserve careful consideration. Thus, 10 per cent of the men had either missing teeth, extensively treated caries, or poor occlusion. Ten per cent of the men showed advanced pyorrhea, while 5.5 per cent had untreated caries. A former submarine commander made the comment, "In Manila we used to think that Vincent's angina went with submarine service."

Comparing the results of submarine escape training examinations of 1932 with those of 1936, it is observed that in 1936 out of 1748 men examined, 156 or about 9 per cent were disqualified and of this number 8 per cent were unable to equalize pressure. Over a period of 4 years there has been a 50 per cent reduction in disqualifications indicative of an improved physical condition brought about by the adoption of stringent qualifications for submarine duty and by the appointment of specially qualified examiners for submarine personnel.

Referring again to the men with obstructed auditory tubes and particularly to the method used in detecting this obstruction, we have uncovered perhaps the most interesting contribution of submarine medicine to military medicine in general, namely the pressure chamber. By means of the pressure chamber a presumptive test of physical fitness may be made on as many as one thousand candidates daily. Let us examine more closely this interesting test.

Obstruction in an auditory tube prevents equalization of air pressure on each side of the tympanic membrane. This obstruction almost without exception is caused by acute or chronic nasopharyngeal infection. Individuals, therefore, who can rapidly accommodate pressure at the rate of 45 pounds per minute excluding those with patulous membranes, are comparatively free from nasopharyngeal infections. Such fortunate individuals in this age of prevalent upper respiratory tract infection are usually found to enjoy excellent health.

In addition to obstruction of the auditory tubes, blockage of the paranasal sinus passages is accurately ascertained since increased pressure elicits pain in the affected sinus.

It may be well to consider the pain producing mechanism in obstructed sinuses and ears. If, for example, an individual is subjected to increased pressure every air space in the body communicating to the exterior is filled with air at a pressure equal to that in the lungs. Thus every air space from the smallest and most inaccessible ethmoid cell to the air cells in the mastoid process receive air, provided that the passages leading to these spaces are open. If a sinus opening or an auditory tube is obstructed, the increased air pressure transmitted through the body acts to stretch the lining membrane and to dilate the blood vessels in the tissue surrounding the occluded space. Pain

is the immediate symptom produced as a result of this stretching and dilating action, and this pain is present in and around the involved area. Pain as a result of pressure changes will be localized even in a tooth containing gas as a result of a poor filling or carious pocket. Localized pain, consequently, as a result of unequalized pressure is a physiologic phenomenon invariably present in the occluded sinus, auditory tube, and even the carious tooth.

As a presumptive test of physical fitness and as a simple method of rapidly diagnosing obstruction in sinus passages and auditory tubes the pressure chamber is of considerable value. Therapeutically it probably has limited value in affording drainage in partially blocked sinuses since recovery from sinusitis is undoubtedly not so much dependent upon drainage as it is upon immunologic response.

Secondary only to upper respiratory tract infection in decreasing the efficiency of submarine personnel is poor dental hygiene. In Pearl Harbor, Hawaii, it was observed that dental caries in spite of a carefully rationed diet progressed faster than on the mainland. Dental hygiene, moreover, is difficult to maintain on a high level during cruises where dishes cannot be sterilized and where limited washing facilities deter even the most fastidious individuals from properly caring for their teeth. It is necessary, therefore, at submarine bases to have the finest dental facilities.

Constipation may be regarded as the occupational ailment incident to submarine service, serious not because it produces manifest physical derangement but rather because it decreases the efficiency of otherwise sturdy individuals. The problem of combating constipation still remains unsolved.

Venereal disease while as serious among submarine personnel as among other groups is handled simply by removing men from the boats until they have been cured. With reference to syphilis the disqualification lasts for a period of 18 months and in gonorrhoeal infection a period of 1 to 3 months which may be shortened by the use of sulfanilamide. It requires but one case of line of duty syphilis to knock out the morale of the squadron.

Mention also has been made of the limited complement aboard a submarine. It is imperative, therefore, that patients be returned to duty without undue loss of time. In a submarine division the medical facilities consist either of the sick bay aboard the submarine tender or a dispensary. It is my belief that these facilities should function as small hospitals manned by medical officers especially trained to treat diseases of the eye, ear, nose, and throat, and of the genito-urinary tract. Transfer of patients to naval hospitals not only results in excessive

loss of time but relegates the function of a medical officer to that of a medical clerk. Men with the highest professional qualifications should be sent, therefore, to these tenders and dispensaries, and particular care should be paid to the professional training of the junior medical officers who engage in the specialty of submarine medicine.

Since three of our submarine bases are located in Panama, Hawaii, and the Asiatic area, the problem of living in tropical climate may be briefly considered.

Continued life in the tropics is either difficult or impossible for a white man. Meredith Townsend in his book, "Asia and Europe," states, "Not only is there no white race in India; not only is there no white colony, but there is no white man who proposes to remain. No ruler stays there to help or criticise, or moderate his successor. No successful white soldier founds a family. No white man who makes a fortune builds a house or buys an estate for his descendants. The very planter, the very engine driver, the very foreman of works, departs before he is sixty, leaving no child, or house, or trace of himself. No white man takes root in India."

According to Drinker the prime disturbing factor inherent in life in the tropics appears to be monotony of climatic conditions. Essentially it would appear that greater effort is required to overcome the inertia that prevents work. Normal men, however, carry on routine duties satisfactorily in the tropics and semitropics provided that a disciplined life is led consisting mainly in decreasing or eliminating the consumption of alcohol, in taking regular exercise, and in securing more rest than is necessary in seasonal zones.

In Hawaii cognizance is taken of these facts. At least 10 forms of athletic endeavor are available at the submarine base at Pearl Harbor where every effort is made to provide an ideal naval environment for service personnel. At this base we have striven in the conditioning of submarine personnel to train men for sea cruises in the manner that men are trained for football games. We believe that the rigid physical and mental preparation of men for cruising at sea is as important as the provision for ammunition, fuel, and food. We hope to see farewell parties eliminated and in their place 10-day periods of conditioning and rest in which men are primed for any prolonged cruising at sea. This hope rests not on any nebulous hypotheses but rather on the practice in the German submarine service during the war when 10-day periods of complete rest and recreation enabled the men to withstand repeatedly the hazardous, arduous sea cruises.

There is, however, in Hawaii an easily overlooked condition destructive of morale and efficiency and perhaps considered beyond the

control of naval administrators. This condition consists essentially of the poor housing makeshift and the transportation problem thrust upon many of our enlisted married personnel who pay excessive rentals to even exist in Honolulu's slum environment. That there should be this problem at all is remarkable in view of the fact that a 12 mile area largely devoted to raising sugar cane is interposed between the submarine base and Honolulu where these enlisted men live. The land, therefore, is available for a compact housing unit adjacent to the submarine base.

From the humane point of view it would appear that the right of naval enlisted personnel to care for their families in decent quarters near the submarine base should supercede the present policy of utilizing all available land for agricultural purposes.

From a military point of view this scattering of naval personnel throughout alien districts would appear to be an unwise circumstance especially in time of war. Further this condition is not conducive to carefully controlled rest periods in port necessary as shown by world war experience to maintain a submarine's wartime cruising radius. *Here is a military problem as important as the fuel capacity of the boats in which the men serve. Here is a medical problem that demands the eradication of a pernicious source of physical and mental ill health maintained by slum housing conditions.*

We may now consider the most important aspect of submarine medicine, namely research. I shall briefly review the results of some of these research studies during the past five years.

The first problem concerned itself with the cause of accidents connected with submarine escape training. When men died following rapid ascents to the surface from depths of 30 feet or less, the cause of death was at first obscure. It was not readily comprehended that a frightened man rapidly shooting to the surface could rupture his lungs by holding his breath and as a consequence force air into the pulmonary blood vessels. That air embolism from excessive lung pressure produced these accidents was proved experimentally in dogs by overdistingending their lungs and collecting air from the carotid arteries which, of course, had entered the blood stream from the pulmonary circulation. Further, the finding of air emboli at autopsy in victims of escape training was strong presumptive evidence that air entered the blood vessels as a result of excess pressure in the lungs.

It was my unfortunate experience to witness a death resulting from an ascent to the surface from a depth of only 15 feet. From this depth the greatest possible potential excess pressure in the lungs would be about 7 pounds, but in some individuals, undoubtedly, air under pres-

sure in the lungs passes rapidly into the pulmonary circulation. Death in fact has been reported to occur in trombone players from air embolism.

On the other hand escapes from a depth of 100 feet have been made without apparatus taking care, however, to release excess air in the lungs about every 10 feet. Holding one's breath during such an ascent produces an uncomfortable sensation of substernal stretching which is immediately relieved by expiration.

During the war a German submarine captain (Wenninger) and some of his crew escaped from their boat which had struck a mine and lay at a depth of 38 meters off Dover. Wenninger's report of the incident is a brilliant example of presence of mind and clear thinking under trying conditions. His report reads, "I decided to take the following measures: First to increase the pressure in the boat and to leave the boat as soon as the hatchway covers could be opened. Admission of compressed air from the torpedo flasks turned out to be insufficient and equalization of pressure was obtained by flooding the boat. It took about 1½ hours from the time of the detonation until the hatchway could be opened.—It was, however, terribly, terribly trying on account of the constantly increasing difficulty in breathing combined with aching pains in the ears and irritating coughing due to gases discharged by the flooded batteries. Two men could not stand the strain any longer and shot themselves. I myself thought of taking morphine but was persuaded by my watch officer Dollman not to do so and to stand it a little longer.

"The water was in the boat at a height of about a foot above the floor plates, when I once more tried to open the hatchway. Suddenly the hatchway cover was torn out of my hands and flung open. I could just shout 'Hold on' and then I was lifted without any effort on my part out of the hatchway where I remained for a short moment without getting wet. I stood in front of a dark, black-greenish wall, through which the outlines of the conning tower were perceptible. Then the water broke all over me and I commenced to rise. To inhale deeply previously had been impossible due to the difficulty in breathing and the exertion trying to open the hatchway cover. While rising I had the sensation of constantly increasing in size. I was curious to see how long I would be able to hold my breath and was astonished to observe that I had no desire to inhale, but to forcibly exhale so that I had to blow air out of my cheeks constantly. (Looking back upon what happened is easily understandable because I had air at 3.5 atmospheres excess pressure in my lungs, which while rising expanded gradually.) I therefore commenced to check my ascent to the surface by energetically

moving both hands. How long it took before I came to the surface, I do not know, and it has been impossible for me to guess at the time. Number two of the group had arrived at the surface before me, and within about two seconds more, all of the eight men had been shot out of the conning tower hatchway like corks out of a bottle. A short time later the men from the fore compartment hatchway appeared. Of these some

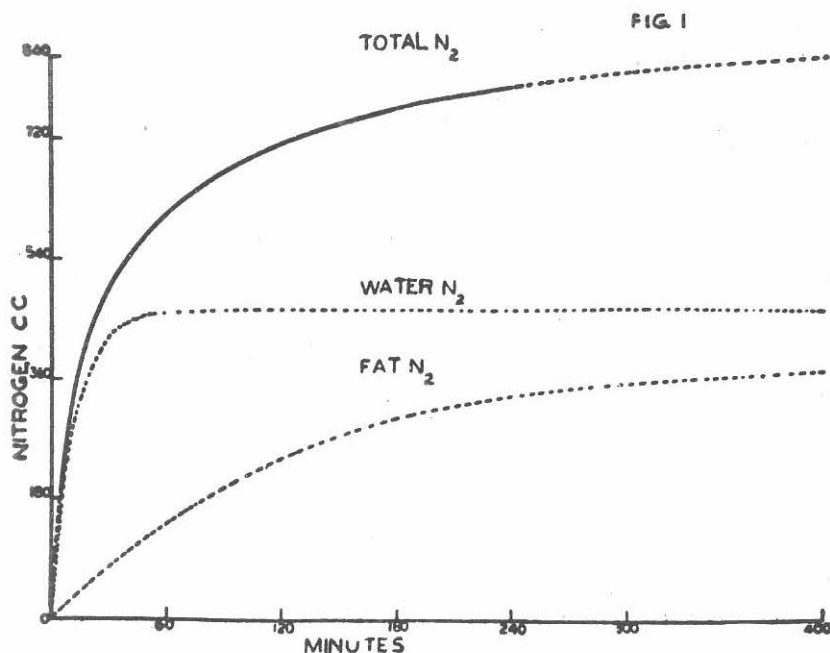


Fig. 1. Solid line shows nitrogen elimination from a young, well developed man weighing 60 kilograms. The nitrogen in the body is soluble in fat and fluids. The elimination or absorption of this nitrogen with changes in barometric pressure is represented by the hypothetical, broken-line curves in the graph. (Reproduced from the American Journal of Physiology.)

with a terrible scream went down again. This I explain by the fact that their bodies were internally bursted by holding their breath. My surprise was great, when at the surface my swimming vest was filled with air to the point of bursting. (Reasoning out what had happened, the same conditions had affected my lungs.)" The captain and surviving members of his crew were rescued after swimming in water (temperature 4 degrees centigrade) for one and one half hours.

The question may arise, why do men sometimes shoot to the surface holding their breath while wearing an escape appliance? The answer to this question is fundamentally, *too much resistance is encountered while*

wearing the appliance. Pressure measurements made with a mercury manometer in actual ascents showed the development in the breathing bag of pressures under certain conditions as high as 60 mm. of mercury. It is obvious that such resistance to respiration soon fatigues the respiratory center of susceptible individuals, who when frightened shoot to the surface holding their breath.

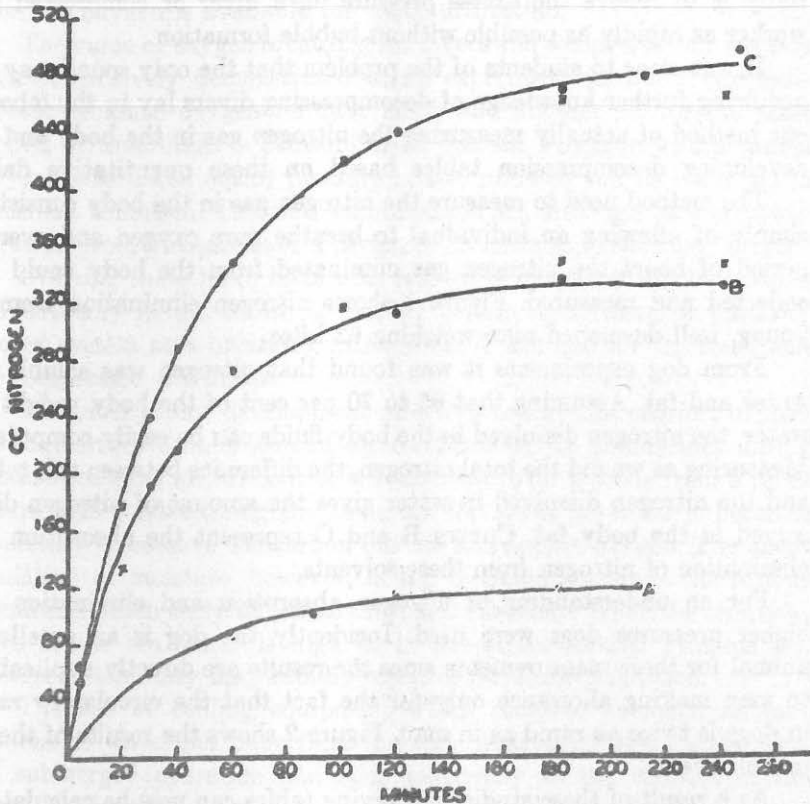


FIG. 2. Nitrogen elimination from the same dog saturated with air at 1, 3, and 4 atmospheres' pressure. Circles represent experimental values. Crosses represent the values which would be obtained if the quantity of nitrogen absorbed at 1 atmosphere is proportional to the quantities of nitrogen absorbed at 3 and 4 atmospheres. Within the limits of experimental error it is seen that this condition is fulfilled. Henry's law, therefore, dealing with the absorption of gases by liquids is applicable to the absorption of nitrogen by the body.

From these accidents we learned as did the doctors who worked with gas masks during the war, that any breathing appliance that offers appreciably increased resistance to respiration, although apparently

perfect mechanically, will not and can not be endured even though the penalty of removal is death.

The next research problem concerned itself with deep sea diving. It has long been known that a diver under pressure absorbs nitrogen from the air and that if ascent to the surface be too rapid this excess gas will form emboli causing bends, i.e., excruciating pains in the extremities, and frequently paralysis and asphyxia. The problem essentially is to relieve the excess pressure on a diver or compressed air worker as rapidly as possible without bubble formation.

It was clear to students of the problem that the only sound way of acquiring further knowledge of decompressing divers lay in the laborious method of actually measuring the nitrogen gas in the body and of developing decompression tables based on these quantitative data.

The method used to measure the nitrogen gas in the body consisted simply of allowing an individual to breathe pure oxygen and over a period of hours the nitrogen gas eliminated from the body could be collected and measured. Figure 1 shows nitrogen elimination from a young, well developed man weighing 62 kilos.

From dog experiments it was found that nitrogen was soluble in water and fat. Assuming that 65 to 70 per cent of the body weight is water, the nitrogen dissolved in the body fluids can be easily computed. Measuring as we did the total nitrogen, the difference between this total and the nitrogen dissolved in water gives the amount of nitrogen dissolved in the body fat. Curves B and C represent the absorption or elimination of nitrogen from these solvents.

For an understanding of nitrogen absorption and elimination at higher pressures dogs were used. Incidentally the dog is an excellent animal for these measurements since the results are directly applicable to man making allowance only for the fact that the circulatory rate in dogs is twice as rapid as in man. Figure 2 shows the results of these measurements.

As a result of these studies our diving tables can now be calculated on sound physiologic knowledge. The new tables essentially will decrease the time of decompression for short dives and lengthen the time of exposure for long dives compared with the present tables developed from empirical knowledge.

With respect to the treatment of compressed air illness the use of oxygen constitutes a life saving measure. The problem concerning oxygen breathing, however, was to determine the limits within which it could be breathed without inducing toxic symptoms characterized by convulsions and pulmonary edema. Fortunately it was determined experimentally that the safe limits for breathing oxygen permitted its use in the treatment of compressed air illness.

Oxygen can also be used in routine diving operations thus replacing air and thereby eliminating the necessity for decompression since nitrogen is not present for the formation of emboli. With reference to the use of oxygen in routine diving operations, exposures up to 30 minutes, provided that carbon dioxide is rigidly excluded, in depths approaching 100 feet can be made repeatedly without subsequent decompression.* Oxygen bubbles do not form under these conditions, or if they do form, the free oxygen is available for tissue utilization.

The value of oxygen breathing for divers and compressed air workers was conclusively demonstrated in an experiment in which one individual breathed oxygen for four hours and another air for the same period of time under a pressure of 30 pounds. The man who breathed oxygen was taken out of pressure in two minutes and he remained in excellent condition. The man who breathed air, although he was slowly released from pressure over a period of 55 minutes, developed "bends."

Utilizing these basic facts with respect to oxygen it will be feasible undoubtedly in the future to employ helium in a closed or partially closed system as a breathing mixture for divers and for the treatment of compressed air illness.

The most recent development affecting health and comfort of men in submarines centers around air conditioning. In submarines during submerged runs air, of course, is rebreathed over periods from 3 to 24 hours. After rebreathing the same air for about 15 hours it becomes necessary to remove the carbon dioxide and supply oxygen. The accumulation of moisture, however, in the recirculating air is the serious condition which early affects comfort and efficiency. When the temperature of the sea water is high as in operations around Panama the increased humidity may rapidly result in physical exhaustion.

The use of cooling equipment which removes as much as four gallons of water per hour from the recirculating air extends the time of submerged operation and adds materially to the comfort of the crew. Of interest in studies of physical efficiency under varying air conditions is the employment of a thermometer to measure the temperature of the air layer next to the skin. Irrespective of external factors of temperature and humidity the air layer next to the skin (termed by Yaglou, "The personal climate") forms an excellent index of an individual's comfort. When, for example, the temperature of this air layer approaches 97 degrees F. an insufficient gradient is produced between skin and air temperature to permit proper elimination of heat from

* In order to allow an ample margin of safety the partial pressure of oxygen in practice would be limited to 3 atmospheres absolute. For work under higher pressures nitrogen or helium would serve as oxygen diluents thus ensuring a maximum working period with a minimum decompression.

the body and collapse of the individual becomes imminent. A temperature of 95 degrees in the air layer adjacent to the skin must be considered as maximum for proper heat diffusion if work is to be done, while a temperature of 79 to 81 degrees F. in the aerial envelope assures maximum comfort.

A few concluding statements should be made regarding medical research in the Navy. The medical problems, especially those in submarine medicine are specifically naval and will only be solved by naval doctors. Research in urology, obstetrics and gynecology; or other divisions of medicine is so thoroughly undertaken by civilian institutions that the Navy need only concern itself with the application of results. In contrast, research in air conditioning as it applies to naval vessels, in the effects of high air and oxygen pressures, in the treatment and prevention of compressed air illness, in the efficiency of personnel engaged in naval manouvers, and research leading to the development of adequate oxygen breathing apparatus for divers and aviators, demands intense application from naval doctors trained in investigative endeavor. If they do not solve them no one else will.

Further, a naval problem is not solved by merely producing conclusive experimental results but by the application of these results, hence concerted support must be given investigators in putting into immediate practice their proved findings. Naval research is arduous and requires continuous effort for the production of results. Such relatively unimportant considerations as rotation of duty should not be allowed to interfere with the research endeavor of trained men or to prevent the application of their results.

In conclusion, may I recall that submarine duty exposes men to crowded, unhygienic conditions of living, particularly to varying climatic factors, and to increased upper respiratory tract infection resulting from rapid climatic changes and from rebreathed air under submerged conditions.

Submarine activity requires alert men highly trained in specialized duty, and since the submarine complement is reduced to a minimum, no man can be spared without decreasing the efficiency of operations.

May I emphasize that in view of these conditions the demand is made upon the medical officer to select the finest men in the service for submarine duty, *to select essentially the rugged, alert individual who does not get sick.*

From the point of view of submarine medicine progress has been made as a result of the support accorded research endeavor by the Bureau of Medicine and Surgery, and progress will continue to be made in proportion to the backing that is given medical officers who enter this specialty.

The writer desires to acknowledge the excellent comments of Lieutenant W. J. Holmes, U. S. N. Ret., which have been frequently quoted in this paper.